Test-System Development Guide

Introduction to
Test-System Design

Application Note 1465-1

Agilent Technologies

Pathways to exceptional test

Functional test is fundamental to the electronics world. In the past, test has been treated as a necessary expense, but enlightened companies have realized that test can be a significant asset. For example, rather than using the test system to simply verify the limits of the device under test (DUT), you could use it to:

- find the weaknesses of the device—before your customers do
- predict failures or out-of-spec trends in production
- search for the boundaries of the design—to stretch specifications or search for something you didn't know the product could do
- verify the long-term characteristics of the product
- optimize a production process
- test for environmental limits
- find the weaknesses in a competitor's product

Test can be used simply as a gating factor for "good" or "bad" devices, or it can be used to gain a competitive advantage. This application note is the first of a series that will give you an overall view of how tests are made, techniques to optimize tests, and a number of methods you can use to your advantage. Other application notes in the series will cover topics such as hardware architecture, choosing instruments, software architecture, computer I/O and connectivity, assembling a test system, maximizing throughput, and optimizing deployment and maintenance.

Some of the latest instruments, such as the Agilent 33220A function/pulse generator, include USB, LAN, and GPIB interfaces, providing you great flexibility in making interconnections.

A systematic test-system design process as outlined in these application notes will assist you to quickly design a test system that produces reliable and repeatable results, meets your throughput requirements, and does so within your budget. For further information regarding test-system design, refer to the book *Test-System Design, A Systematic Approach* by Tursky, Gordon, and Cowie (Prentice Hall, 2001). Much of the information in this application note was derived from this book.

This application note covers the three primary sectors of the product life cycle that require test: R&D, design validation, and manufacturing.

The earlier a product weakness is discovered, the less expensive the consequences. That's one reason why the role of test changes with the stage of the product life cycle. When a product is first developed, the role of test is to verify that the design concept is viable. This calls for quick measurements, usually with hands-on use of discrete test instruments. Sometimes there is a need to load measurement data into an Excel spreadsheet for use in a lab report or for further analysis.

Excel is the most common software analysis tool for the R&D engineer. The connection is usually simple: a PC connected via GPIB or USB to an instrument or a small set of instruments. Simple software, such as Agilent Intuilink, finishes the connection.

Once the design becomes more solid, there is a need to find its limits and weaknesses. That's where the design validation system comes in. To make the results more repeatable and less dependent upon operator expertise, the test system is automated using a PC and some sort of graphical software such as National Instruments LabVIEW or Agilent VEE.

Graphical software, often used for design validation testing, gives the engineer a more comprehensive set of tools for control and analysis, while at the same time creating a more repeatable measurement process that may include remote control of sources, measurements, and system switching. The same instruments used in the R&D bench system are often used in design validation. This gives continuity to the whole process, so that the initial R&D measurements can be compared to those made for design validation.

Textual software generally provides an effective programming environment for manufacturing test, as it enables the engineer to extract the highest throughput from the test system. In manufacturing, repeatability and reliability become paramount concerns. Again, if the same equipment can be used for all three test situations (R&D, design validation, and manufacturing), then the R&D engineer can more readily assist with any problems that may arise during manufacturing test.

The process of designing and integrating systems used for electronic test requires more than simply coding instrument commands to automate the measurements made on the R&D bench. The instruments are only one part of the complete test system; cables, software, test-plan documentation, and fixturing are equally important. The latter are especially prevalent in a manufacturing environment.

Test-system design requires more input than test specs

There are many factors to consider when developing a test system. The three main driving factors are test requirements, development time, and test cost. The factor that is most important will drive the other two. For example, if the test requirement is for a very accurate measurement, as in R&D or design validation, you must be willing to take a bit more time and spend more to achieve the required accuracy. On the other hand, the manufacturing manager would not be pleased if the test system were to perform more tests than required, or perform them at a higher-than-needed level of accuracy, due to the obvious impacts on test-system cost and throughput.

Before the process to design a test system can begin, you must have a good understanding of the test application. This goes beyond simply understanding the device you are testing, as you must also be aware of other factors such as the skill level of the test system operator, the operating environment, and any standards requirements.

A test plan guides test-system development

Creating a comprehensive test plan allows you to take a big-picture view of the project and forces you to focus on meeting the objectives and requirements for the test system. The result is a considerable time saving in the development process.

Even in the R&D environment, there are times when it is useful to create a test plan, so that you can document and compare results after each design cycle. You must also consider the future for any test system you create today. It may be reasonable to create a dedicated and somewhat inflexible test system on some high-volume projects, but it is usually more appropriate to create a system that has the flexibility to adapt to future needs.

The test plan describes more than just the requirements of the DUT. It should also cover other areas of the test such as the level of experience required of the test system operator, calibration and maintenance requirements, physical limitations, and throughput requirements.

So the first step in creating a test system is to seek out and compile all the information needed to create an overall test plan. Important information includes:

- functional and parametric tests to be performed
- DUT design validation criteria
- format and usage of test results, including sharing data throughout the enterprise
- number of tests
- DUT pin counts
- physical constraints such as size, environment, and available power
- heat buildup and power dissipation
- how the test system will be verified, maintained, and calibrated
- RF environment
- accuracy and resolution requirements
- throughput goals
- development time constraints
- software-development and runtime environment
- cost constraints
- continuity constraints with existing legacy systems

Among the decisions involved in determining the design of a test system, the most obvious is what it is you must test. This is usually defined in a test specification. The test specification should include a complete list of the product functions to be verified, operating parameters to meet, and any regulatory standards to adhere to.

Accuracy

System accuracy is a critical specification of any test system, and the overall test plan should include both the accuracy requirements of the test and the recommended margin. As a minimum, the test equipment should have twice the accuracy specified for the DUT. To maintain this margin requires that the operating temperature be maintained closely and that calibration cycles be followed faithfully.

Often, it is more cost effective to buy test equipment with a 10X accuracy margin so that calibration and maintenance requirements can be relaxed without affecting accuracy. In the "10X" case, you may even increase the product yield, since the product can come closer to its specification tolerance limits because you can count on the accuracy of the test system. Whatever the accuracy required, you must have confidence that you can rely on the results.

Obviously, a calibration and maintenance plan is important for achieving the required test accuracy.

When determining instrument requirements, resolution must be specified as well as accuracy. Accuracy defines how close a measurement agrees with a standard value. Resolution indicates the smallest change that can be measured. There may be times when the absolute accuracy over an extended period is not as important as the resolution to measure small changes over the short term. Switching, fixturing, and cabling also add noise and crosstalk that can increase uncertainties.

Throughput

Throughput requirements will direct the necessary system capacity. Throughput is normally more important in the manufacturing environment than during design validation and rarely a concern in R&D. However, some complex designs require lengthy testing to be validated before going into production. A significant delay during R&D or design validation can cause a product launch to be delayed, and be costly in terms of missed market opportunity.

Downtime seriously degrades test-system throughput and can have a significant impact on product shipments. Predicting and preparing for wear-out mechanisms can reduce downtime. Further, using diagnostics or built-in test can help determine when the test system is about to fail. Such preventative maintenance procedures can result in big savings when they identify a test system failure before many DUTs are erroneously tested. In all cases, whether in R&D, design validation, or manufacturing, you should consider how you will handle downtime, either with spare test equipment or with a known path to repair or rental.

The overall test plan is a good place to describe what diagnostics the test system will require. It is easy to overlook test-system diagnostics as time consuming and costly to develop. Diagnostics are an important tool for maintaining throughput by reducing the downtime to repair failures. On most systems, a well-thought-out diagnostics approach will shorten test-system deployment time as well. Developing and following a calibration and maintenance plan in conjunction with the diagnostics is another way to prevent system failures that disrupt test-system throughput.

Results

All tests must produce results. Sometimes this is merely a simple pass/fail indication, but often test results must be analyzed and archived. These requirements must also be defined in the overall test plan. If the test sequence is short, a few minutes or so, it is simpler to perform all data analysis after the test is over. However, if the test sequences are lengthy, some intermediate data analysis is recommended so that failing functions can be detected early enough to halt the test and avoid wasted time.

Test system-design decisions

Once the requirements of the test system have been established in the test plan, then it is time to outline the design of the test system itself. The question is: What to consider first—software or hardware? In the past, the hardware provided the lead in test-system development. The test instruments that met the accuracy and throughput requirements were defined first, and then software was created to automate the test system. But today, software can often be more expensive to develop than the cost of the hardware, so if test system cost is a driving factor, it is important to make sure that a new system can use as much existing software as possible.

The choice of programming languages may be based primarily on the experience of the programmer. Some find graphical languages such as LabVIEW or Agilent VEE easy to use. Others believe that textual languages such as C++ or Visual Basic are easier to use, especially for complex test programs. If it is important to use existing textual test code, then a multi-language development environment like Microsoft® Visual Studio .NET is a definite advantage. In any case, it is critical to ensure that drivers (for example, IVI components) exist for the selected equipment. If the required drivers and support are not available, the anticipated advantages provided by the selected language may not materialize.

Control

A major consideration for a test system is the level of automation to build into the system to control the test process. Manual control requires that a human operator make all of the test connections, set the instruments, and then record the data. Increasingly, even in simple R&D setups, most engineers prefer to use instruments under the control of a PC in order to have a record of the test.

Once the testing becomes more complex or repetitive, a fully automated test system is in order. A fully automated test system takes care of signal switching, measurement, recording, and even analysis of the results for pass/fail determination. Once the DUT is in the test fixture, the test system takes over and runs all of the tests. This is the ultimate in terms of test speed, reliability, and repeatability, but it is also the most expensive and time consuming to develop.

The type of control, either manual, semi-automated, or fully automated, should be determined early as it will influence which instruments you select. As shown in **Table 1**, many factors will affect which control method is most suitable for your application:

- cost
- volume of tests
- test speed
- future uses
- upgrade path
- operator experience

Manual control

A test system based on manual control depends entirely on the operator for all test functions **(Figure 1)**. Connections between the DUT and instruments are made manually with test leads or cables. R&D engineers may follow procedures that are completely undocumented, but when using a manual control system for other test requirements, each instrument is normally manually operated by following a documented procedure. The results of each test are then manually recorded. This is a

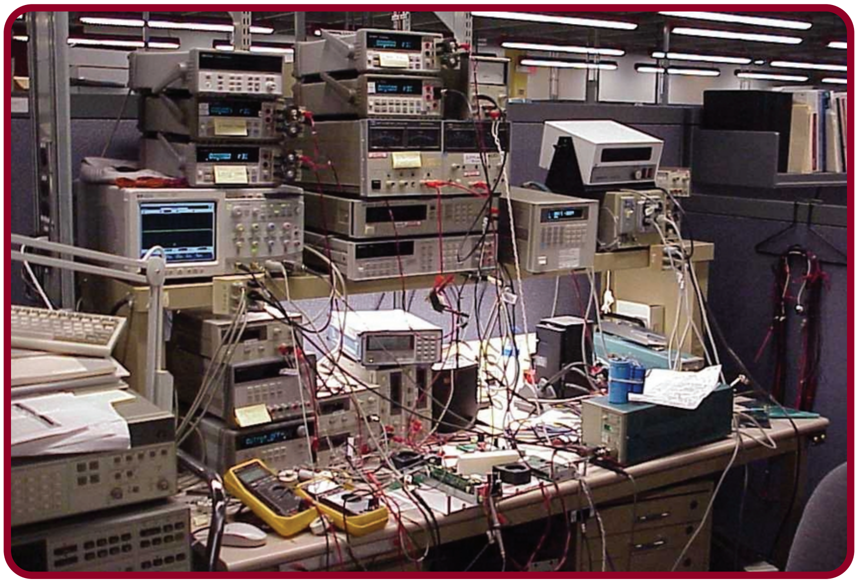


Figure 1 A test system using manual control requires a skilled operator

Table 1. Comparison of test system control options

	Manual	**Semi-automated**	**Automated**
Instrument cost	Depends. Can be higher than automated, since R&D typically needs more accuracy than production specs.	Similar to manual.	Depends on requirements. If space is paramount, cardcages can be used, but they are typically more expensive than standalone rack & stack instruments.
Development cost	Very low, just hook up and go	Low or high depending upon how much is automated	High
Operator experience	Very high, often experienced engineers	High as the manual portions of the system may require an engineer	Low
Development time	Low	Low to high	High
Flexibility	High, changes can be made easily.	Medium, some portions can easily be changed.	Low, changes require significant effort.
Throughput	Low	Medium	High
Repeatability	Varies with expertise	Medium	High
System calibration	Rare. Usually only each instrument is calibrated.	Some system calibration may be possible.	Full system calibration is possible.
Self-check diagnostics	Individual instruments only, not system diagnostics	Individual instruments only, not system diagnostics	Common
Ease of instrument reuse	High	Medium	Low if card cage, medium if stand alone instruments
Potential for human error	High	Medium	Low

very flexible approach as it allows changes to the test system to be made very easily. On the other hand, it is a very slow method of testing and has significant problems with repeatability. For example, the engineer may make readings one time with the voltmeter at full scale, while the next reading might be at 1/10 of full scale, resulting in a slightly different answer.

Manual control is often the least expensive test-system control option to set up, since it may not include such items as a system switch, expensive software, or test fixtures. Also, the time and cost required to set up the test are very low. However, the instrument cost for manual control varies. Often, the R&D application calls for a more accurate measurement than the equivalent measurement needed in manufacturing and therefore requires rather expensive instruments. The cost to conduct the test is usually very high. Manual control generally requires a skilled operator to follow the labor-intensive test procedures. System self-testing is almost impossible, and complex and frequent calibration is often required due to the high accuracies needed. Typically, only the individual instruments are calibrated and not the entire system. As a result, inexperienced engineers may believe that the overall system accuracy is better than it actually is.

Repeatability is a concern with manual test systems. There are many opportunities for operator error to go unnoticed. These errors creep in when the operator is attaching cables, setting instruments, recording results, and even when transferring the results to other documents.

Even with these limitations, the manual approach can be useful. With due diligence while conducting the test and techniques such as using the same cables to increase repeatability, the manual approach can produce reasonably reliable results. Another advantage of manual control is the ease in which the test system can be reconfigured or the instruments used for other projects.

Additionally, a skilled engineer conducting the tests is constantly comparing the results against expectations, thereby providing a form of continuous verification of the test system. An incorrectly operating fully automated test system could continue to test for hours, days, or even weeks without detecting the problem, resulting in the shipment of incorrectly tested products.

Use manual control when:

- cost of automation outweighs benefits
- speed of test is not critical
- test requirements may change regularly
- the delay to create an automated system is unacceptable
- skilled operators are available
- the instruments need to be easily disassembled for use elsewhere

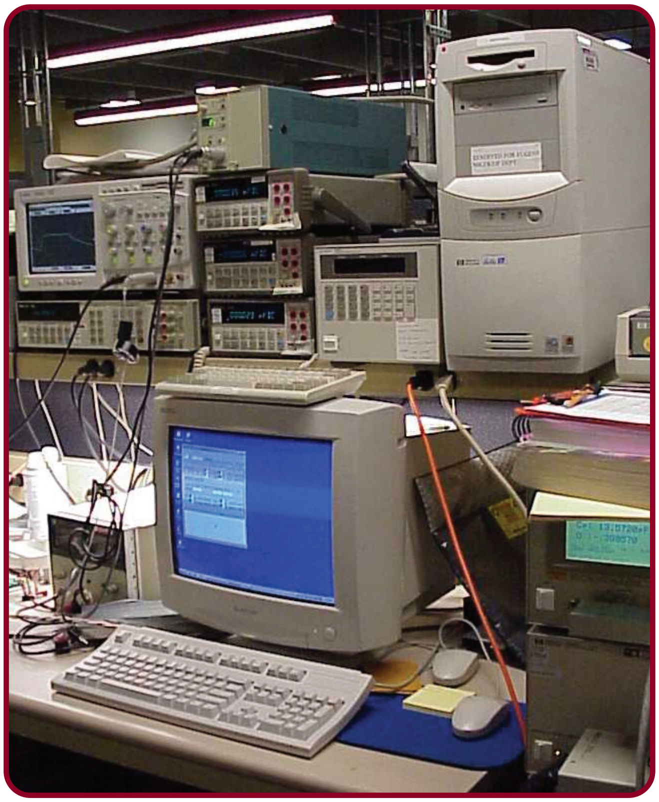


Figure 2
A test system using semi-automated control often uses a PC for the operator interface.

Semi-automated control

Semi-automated control is the most common type of control approach used for test systems, and is useful in R&D, design validation, and manufacturing test **(Figure 2)**. Test systems using this control approach have manual portions for flexibility where it is needed and automation where it makes sense. Those sections of the test system that are expected to change often or would be too expensive to automate can be manual. Those sections that will not change or would benefit from automatic data recording can be automated.

A semi-automated test system might require the operator to manually connect the DUT, provide instructions to the operator for the procedural steps, and automatically record the results. For example, a semi-automated system might have an oscilloscope and an RF source that are under computer control, with a power supply under manual control. The engineer would vary the voltage to the DUT via the power supply, run a set of tests at this voltage level, and then manually change the voltage and run another set of tests.

Semi-automated control is often much faster than manual control and produces a more reliable and repeatable result. This method of control can take advantage of simplified software development with Agilent's VEE or Visual Studio .NET for quickly creating the required automation.

The most common type of test equipment includes a fully functional front panel and a computer interface that allows both manual and automated use. This is a major benefit, even when automating, as you can always go back to a manual approach if you need to measure other parameters, troubleshoot the system, or conduct an experiment. These standalone instruments are beneficial when developing a fully automated test system for manufacturing as it is common to start with a semi-automated system and then increase the level of automation as experience and production volume increases.

Use semi-automated control when:

- automation benefits will outweigh added costs
- test volume does not require full automation
- some flexibility in the test system is required
- reasonably repeatable results are required
- skilled operators are available or close by
- a move to full automation is anticipated but not yet required

Automated control

Fully automated test systems are the domain of complex design validation testing or the manufacturing test environment **(Figure 3)**; they are rarely used in R&D. All of the instruments, signal switching, and connections to the DUT are controlled by computer. In some automated test systems, an operator may be required to manually install the DUT into a test fixture as a single action, but others have an automated handler to insert and remove the DUT from the test fixture.

Full automation is the most expensive control method in terms of software development time, but it also results in the highest throughput and most repeatable and reliable measurements by nearly removing the human-error factor from the test. The skill level required of the operator is usually much reduced.

Full system calibration and diagnostics are easier to implement in an automated system where software can reconfigure the test system to allow it to test and calibrate itself against an external traceable reference. Full system calibration can even calibrate the cables and connections instead of just the individual instruments.

Proper diagnostics designed into an automated test system can test most of the system. You can create a diagnostic device that plugs into the DUT fixture. This device will connect test stimulus signals to test measurement instruments. Diagnostic software you create will then configure the test system to verify operation through the same switches, cables, and connectors that are used for testing.

Figure 3
A fully automated test system requires minimal operator interaction.

There must be compelling reasons to justify an automated test system. Not only is the initial development cost high, but any changes or upgrades to an automated system can be very expensive. The compelling reason for the expense is usually the high-volume requirements of manufacturing test, but there are times during R&D and design validation when the required accuracy is very high or the test is very complex, making it necessary to automate the test to remove potential human errors or speed up the test process.

Use fully automated control when:

- high-volume manufacturing requires automation
- reducing test time is critical
- test requirements are known and stable
- cost per test outweighs test-system development cost
- time is available for development
- skilled operators are not available
- accuracy or complexity requirements dictate automation

This test system was used to demonstrate the performance differences between USB, LAN, and GPIB interconnections to the Agilent 33220A function/pulse generator.

Planning for the future

When making test-system design decisions, you should keep future needs in mind. Upgrades are a fact of life for a test system. They can be very expensive and time consuming but are often unavoidable. Naturally, any upgrades must justify the expense and effort required. Some of the reasons for upgrades are to:

- accommodate changes in design of the DUT
- conduct additional tests
- obtain higher accuracy
- obtain higher throughput
- eliminate redundant tests
- rearrange the test sequence to detect failures earlier
- improve analysis
- automate more of the test
- decrease the skill level required to operate the test system
- replace obsolete equipment
- change reporting requirements
- upgrade the operating system
- conform to new standards
- add newly developed models
- repeatability is important

A few moments considering the future can have a significant impact on future options. For example, when selecting instruments for a manual system, there is usually very little added cost to select instruments that have computer interfaces. You may not need the interface today, but computer control is not possible without it (and could be costly, difficult, or even impossible to add at a later date).

Using open standards will increase the likelihood that test system components will be useable in the future. Proprietary interfaces have a habit of disappearing or not supplying the drivers you need for future software options. Using proprietary measurements made by specific equipment in a test system from manufacturers that do not supply future upgrade paths could make an entire test system obsolete if that exact instrument is no longer available.

Following proper software design techniques resulting in well-written software that is easily understood, maintained, and modified is an obvious requirement for future upgrades. Good documentation is also critical to the future of a test system: Chances are you will not be the one that is tasked with future modifications.

Conclusion

Although test-system development is a complex task that can include many aspects of electronic and mechanical design, following a systematic approach and partnering with quality test equipment manufacturers will enable you to enhance your success while lowering the cost and time it takes to create the test system.

Case Study: Testing Power Supplies

This case study is an example of how a test system can evolve from R&D to design validation to manufacturing. Many of the same instruments are used in all three areas with the major difference being the type of control used. This is a common practice as the knowledge gained in each phase of product development is transferred to the next.

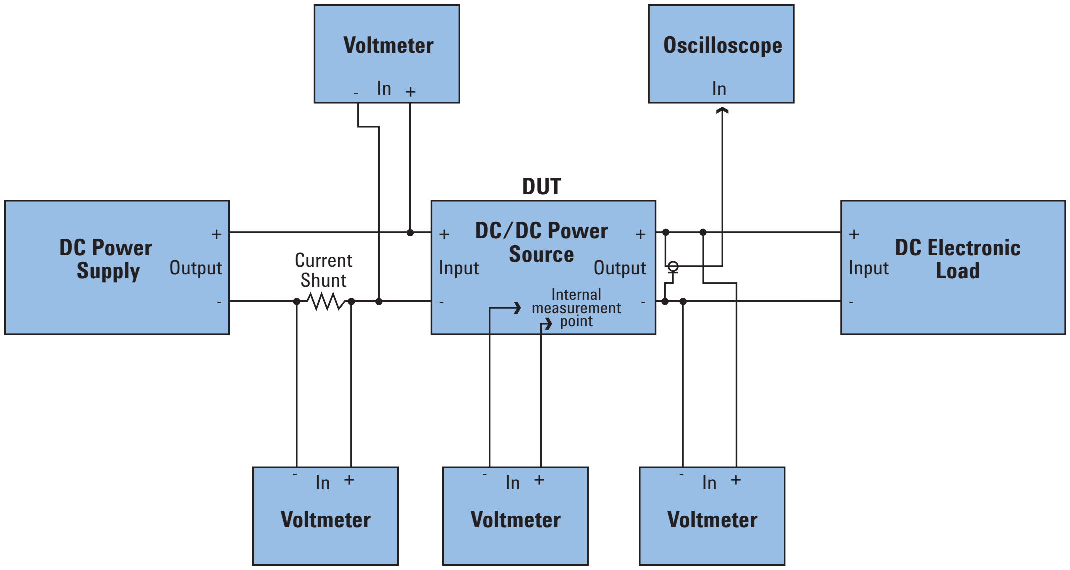
Manual control

When developing a product such as a power supply, the R&D engineer will create a test system as required to explore options and verify results. The test bench in **Figure 1** is typical of such use. Many instruments are within reach and it is easy to rearrange them as needed. All of the connections to the DUT are made manually and each instrument is manually operated. This is an example of a test system with manual control.

The flexibility to quickly move from measurement to insight to next measurement, whatever that next measurement might be, is obvious. Standalone test instruments readily lend themselves to this usage model. The high level of skill required of the operator is also important. There is significant opportunity for error and confusion with a manually controlled system. R&D engineers are in their element at such a bench, but it falls short on reliability and repeatability when compared to other control methods.

The block diagram of **Figure 4** shows the interconnection of the instruments for some of the tests used during the R&D phase of power supply development. Some of the standard tests measure output-voltage accuracy, output noise, load regulation, line regulation, and output programming speed.

Figure 4 Block diagram of a manually controlled test system used for R&D



The test system diagrammed in **Figure 4** is just one example of a manual setup for testing some aspects of the design. Other R&D engineers would have other manual setups on their benches to test for other parameters. In this case, the total R&D manual test system is actually distributed throughout the benches of the entire design team.

More-specialized tests will also be conducted at this stage. Loop gain (Bode plot) is used to evaluate the stability of the control loops used to regulate the output voltage and current of the power supply. Load transient response is measured by applying a load-current step change and monitoring the output voltage on the scope, also giving insight into the stability of the control loops. Voltage and current stress on the components are also measured so power can be calculated to ensure that no parts are over stressed. The temperature of individual components may also be measured.

As these measurements are made, the test system is rearranged, the cables are attached as required, the instruments are manually controlled, and the results are noted. Often, the exact configuration is not recorded, making an exact repeat of the measurement difficult. The cable connections are often made with probes and clip leads in a manner that is quick but not reliable. Even so, the advantages to a skilled operator far outweigh the problems associated with manually controlling a test bench **(Figure 1)**.

Semi-automated control

The design is "complete". Now it needs validation, so the test requirements are somewhat different. In this case, the same instruments are used, but a computer is added for semi-automated control. The block diagram of Figure 4 remains the same, but now a computer is connected to some of the instruments **(Figure 2)**.

Many of the same measurements are made during design validation as were made during R&D. But now, more of them can be made to fully validate the design. For example, the output accuracy of the power supply under test can be checked at a variety of operating conditions. The input voltage, load current, and even the ambient temperature can be varied to ensure proper regulation of the output voltage and that the output noise is within requirements. The same tests can be conducted on multiple prototypes to ensure that the design is consistent across units. Further, these tests can be completed much faster and include automated data recording, enabling statistical analysis.

The repeatability and reliability of semi-automated control along with automated data gathering are a significant enhancement to manual control. By selecting instruments that include computer interfaces, automating portions of the test system is much easier. In many cases, the automation is merely a matter of having a computer perform the commands and read the results that were done by an operator.

Automated control

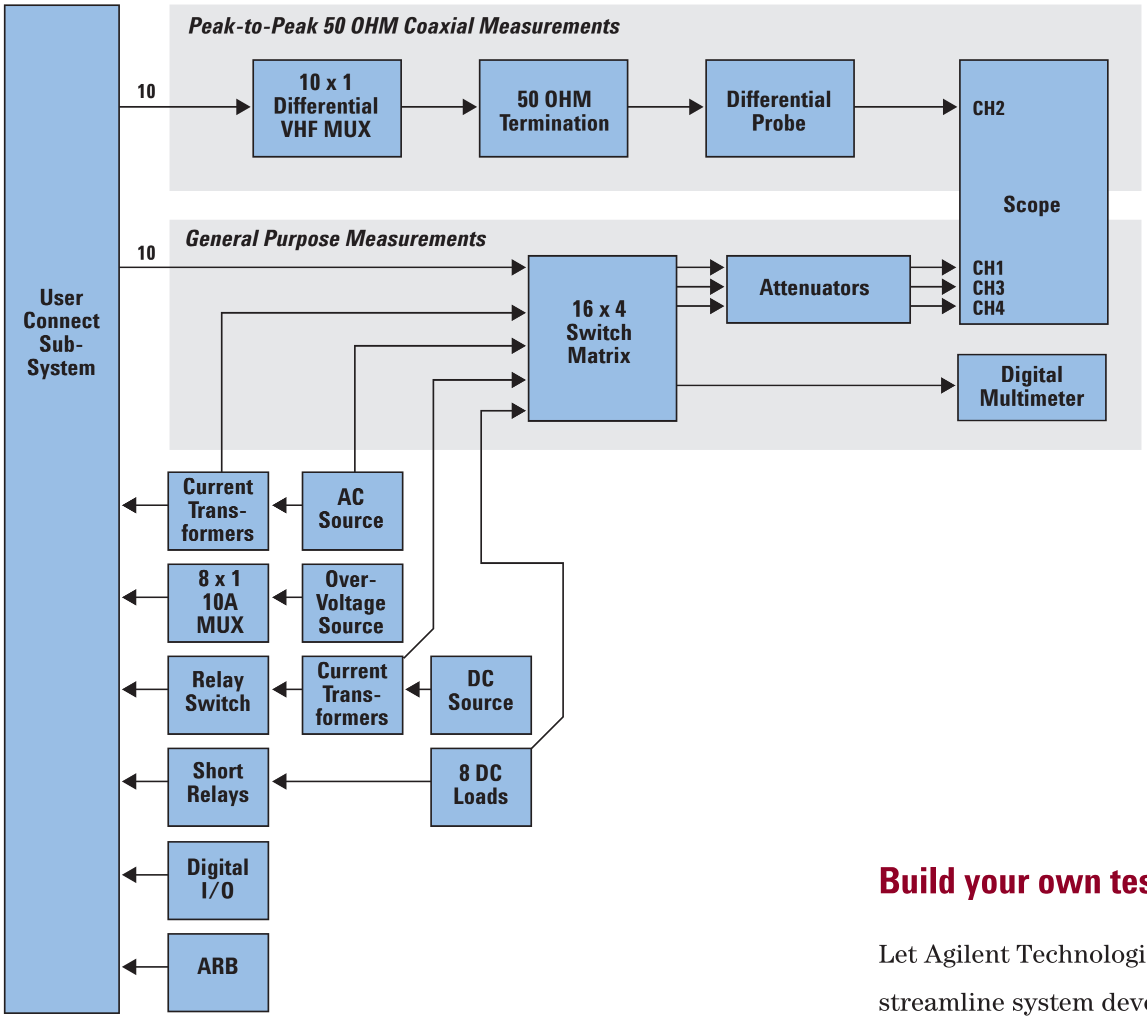
The move to a fully automated test system may require additional instruments, as shown in **Figure 3**. The computer now controls all of the instruments as well as the reconfiguration of the interconnections for various tests. The digital multimeter, scope, and loads are still used, but now switches are employed to connect the DUT to the instruments. As the tests are performed, the computer uses the switches as required.

The block diagram of **Figure 5** includes connections to the DUT and measurements that test the power supply in the manufacturing environment. The number of tests performed may approach those conducted during R&D and design validation but they are normally not as thorough. Manufacturing tests are often performed only at one operating point that is considered to be a worst-case condition. This maximizes the amount of information gained about the DUT in the minimum time.

The speed, repeatability, and reliability of the fully automated system can be significantly better than that of other test system control methods. Also, the skill level of the operator can be less. But the time and expense to create the system and make any changes usually makes automated test systems only feasible for manufacturing uses.

Including a mixed-signal oscilloscope (MSO) in your test system allows you to view time-correlated analog and digital signals in a single instrument.

Figure 5. Block diagram of a fully automated test system



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Related Literature

1 Agilent 33220A 20 MHz Function/Arbitrary Waveform Generator, Data Sheet, Literature # 5988-8544EN http://cp.literature.agilent.com/litweb/pdf/5988-8544EN.pdf http://cp.literature.agilent.com/litweb/pdf/5988-8544EN.pdf

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2. Computer I/O Connectivity Considerations, Literature # 5988-9818EN, to be released in July, 2003
3. Choosing the Test System Software Architecture, Literature # 5988-9819EN, to be released in July, 2003
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